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A Simple and Efficient Way to Detect the Mining Induced Water-conducting Fractured Zone in Overlying Strata

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Abstract

Coal mining operations in China are often threatened by the invasion of the groundwater into the mining panels. The most likely water disaster affecting the safe operation of coal mines is water from Cenozoic porous aquifers in the alluvial plain areas flooding into the mine. The problem will become very serious when the mining-induced water-conducting fractured zone penetrates upwards into the aquifers, since it provides access for water inflow into the mine working panels. Therefore, it is of crucial importance to determine water-conducting fractured zones for predicting and preventing flooding in coal mines during mining. However, most Chinese coal mines have little technical equipment for monitoring such thing or professional staff to use such equipment. Such situations are even more serious in small coal companies. So a simple, manually operated instrument that has the advantage of being intrinsically safe and can be operated in gassy underground coal mines is popular in China. The instrument, named Double-End Blocking (DEB) device, measures the injected water loss rate along the borehole while the borehole is blocked on both ends and water is pumped in it. Comparing injected water loss rate between pre- and post-mining, the water-conducting fractured zone enhancement can be detected because the water loss rate will be larger in the stratum where the water-conducting fracture happened. In this paper we used the instrument to detect overlying strata water-conducting fractured zone height in one coal mine, which operated beneath a water-bearing alluvium. The overlying Cenozoic porous aquifer is a deadly threat. The results show that the instrument provides a simple and efficient method to determine the water-conducting fractured zone.

Key words: gounderwater; water-conducting fractured zone; overlying strata; coal mines; water invasion

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1. Introduction

China has vast coal reserves, and coal continues to be about 75% of china's energy source. Therefore, coal production is of crucial importance for the Chinese economy and development. However, mining operations in China are threatened by various dangers. Many coal mines in China are threatened by the invasion of water during coal extractions. According to the official statistics, there are 600 key coal mines in China and about 285 of them are threatened by flooding during coal mining. Flooding from Cenozoic porous aquifers occurred frequently in Northern China coal mines, which are in the Yellow River and Huai River alluvial plain areas [1][2]. During seam extraction from those coal mines, water accesses the mining area through the mining-induced strata failure and water-conducting fractured zones causing serious water disasters. The consequences are sometimes fatal and could lead to partial or even total loss of a mine.

Therefore, the Cenozoic porous aquifers groundwater invasion hazard is a common concern of both mine operators and researchers. It is of vital importance to determine mining-induced water-conducting fractured zone height variations for predicting and preventing flooding in coal mines. To measure the height in the overlying strata, a number of techniques (such as electric resistivity, ultrasonic wave, acoustic scan, hole televiewer, etc.) are used. Those techniques however are limited by the water filled mining panels and gassy coal mines conditions. These situations often occur in Chinese small coal mines. Moreover, most highly technical instruments, which can accuracy detection water-conducting fractured, are not available because of the lack of professional staff or computer software, particularly in mid size or small coal mines.

The simple and direct way is drilling boreholes from the earth surface and observing the washing liquid loss rate to determine the hydraulics conductivity. The hydraulics conductivity implies the water-conducting fractured zone enhancement. But the boreholes drilled from the earth surface are difficult to put into practice due to either the coal seam being very deep underground or under an existing aquifer. The technique can not be performed in underground roadways limited by the height of underground extraction space. More often underground boreholes are inclined. However, the technique of observing the washing liquid loss rate can't be used in inclined boreholes. So there is a need for a convenient and efficient detection technique which can also be used in gassy mining faces to detect the water-conducting zone under a water bearing alluvium. And the technique can be used in upward inclined boreholes.

2. Detection water-conducting fractured zone of overlying strata

2.1. Water-conducting fractured zone in overlying strata

When a coal seam has been mined, the stress equilibrium around the goaf is broken and redistributed. Mining of the seam causes rock bed deformation, destruction and displacement, and finally results in the movement of an entire area starting from top to bottom. When dealing with the goaf management of the collapse of all the rocks, the entire overlying strata can be divided into "three zones" according to the movement of the rock bed and degree of damage, i.e., the caving zone, the water-conducting fractured zone and the bending zone [3]. The water-conducting fractured zone is formed by rock bed fractures and fissures which retain their former layer distribution and fissures consisting of parallel layers, formed by bed separations and vertical cross fissures formed by rock fractures. The rock bed movement is continuous and integral in the bending zone and the flexibilities of overlying strata are almost the same value. In a vertical section, differences in subsidence become smaller from the bottom zone to up zone. When the rigidity of beneath rock is weaker than that of up layer rock, the rock bed will not be able to carry the load and bed separations take place in the middle of the span between the rocks [4]. Over time, fissures and bed separations will close in the overlying strata and result in land subsidence [5].

In general, all of the caved zone and the water-conducting fractured zone affect overlying strata hydraulic conductivity [6][7]. For mining under aquifers, the water-conducting fractured zone is more interesting, since it provides access for flooding into the mine working faces because of hydraulic conductivity enhancement in this zone.

2.2. The DEB detection technique

With coal extraction, the hydraulic conductivity and the height of water-conducting fractured zone will be enhanced and increased. It is desirable to determine pre- and post-mining hydraulic conductivities in the overburden strata, especially, overlying strata. The height of water-conducting fractured zone will be obtained comparing the pre- and post-mining hydraulic conductivities. The Chinese have developed some specific techniques for measuring conductivities under aquifers and surface water liberating millions of tons of coal reserves without serious water disasters [8]. Among these techniques, the circulation water loss rate method is popular. To determine rock strength, borehole fissure, and changes in hydraulic conductivity according to the method, the circulation water loss rate along the borehole during drilling is measured by pumping water into the borehole and keeping water head. The fractured zone can be detected because the pumped water loss rate is in direct proportion to hydraulic conductivities in strata. The method can be operated easily with little apparatus. However, this method can only be used in surface downward boreholes because the water will run away in upward boreholes. When the coal seam is very deep, boreholes from the surface are not feasible.

To overcome these shortcomings, the Double-End Blocking (DEB) technology was developed and used in an underground observation gate. The DEB device can work in an upward inclined borehole. This instrument can detect the hydraulic conductivity in underlying strata and in overlying strata as well. The key technique during measurements is to block the double ends of the observed area along the boreholes and keep injected water pressure. There are two ballonets at the ends of the observed area. The two ballonets will inflate and the observed area is hermetical when pressurized with air. High pressure water is then injected into the observed area to detect the fractures. The water pressure should not be too high or it may cause new fractures in the strata, since the operation is to detect the changes in hydraulic conductivity induced by mining. Therefore, the injected water pressure should not be larger than the least principal stress of the surrounding strata.

Actually, the DEB detection technique is being used in some Chinese small coal mines.

3. Case study

3.1. General geological conditions and the aquiclude property of Taiping Coal Mine

The Taiping Coal Mine locates in eastern China, with reserve of 104.44Mt. The main coal-bearing unit is 8.0m thick and the oblique angle is 0～8°. Its average depth is 190m. The bedrock layers of the overburden are mainly fine-grained, medium-grained and powder sandstone. It contains little water and appears weathered. The total thickness of bedrock is 10～36m on average. Above the bedrock, there is a 0～6m clay layer overlying Cenozoic loess layers. The total average thickness of the clay and loess layers is 158 m. On the surface of the loess layer, there is a layer of sandy soil. The clay and loess layers serve as an aquiclude in the overburden. The clay layer is discontinuously distributed and rapidly changed in thickness. Once the clay layer is removed, the water of Cenozoic porous aquifers, stored at the bottom of the loess layer, can directly infiltrate into sandstone of bedrock layer and threaten the safety of the mine.

The property of the aquiclude is the key factor that determines the potential for post-mining water conservation [9]. It is yellow sandy clay with multiple streaks of soils and can be divided into three sub-layers. The top sub-layer is yellowish brown and has porous gravel layers. These porous gravel layers are permeable and water-bearing. The middle sub-layer is gray-green and mainly clayey mineral with little gravel. The bottom sub-lay is off-white, and the mineral contents of the clay and gravel are between the top sub-layer and middle sub-layer. Therefore, the water-bearing capacity and water permeability of the bottom sub-layer are between the top sub-layer and middle sub-layer.

3.2 The instrument application

The 8311 mining panel of Taiping Coal Mine is 120m wide and 662m long, deployed a paste backfill mining that the surface subsidence can be controlled and no buildings removed in mining area [10]. That is considered to improve local and regional stability, enabling safer and more efficient mining of the surrounding areas [11]. The coal extraction of the 8311 mining panel is threatened by flooding from the Cenozoic porous aquifers. The height of water-conducting fractured zone has a positive effect on Cenozoic porous aquifers water inrush and overlying bedrock collapse. Therefore, determining the height of water-conducting fractured zone is important to maintain mine safety. The instrument is used and six underground observation boreholes are drilled pre- and post-mining respectively to detect the height of water-conducting fractured zone in the overlying strata of the 8311 mining panel.

The DEB device was applied pre and post-mining to measure the loss rate of injected water in the four boreholes drilled at different angles. The injected water pressure is 0.4MPa. The water is injected along each borehole by pumping water into the instrument, and then into the borehole. The measurements were taken in each hole at different sections throughout the borehole and at different times. The injected water loss rate differences of the pre-mining boreholes #1, #2 and post-mining boreholes #3, #4, #5 and #6 can indicate information about the height of water-conducting fractured zone in the overlying strata.

4. Result discussion

In the Taiping Coal mining, we used boreholes #1, #2 to detect the original overlying strata fractured before mining, and #3, #4 and #6 to detect the overlying strata fractural after mining. The past-mining and pre-mining water loss rate difference will show the water-conducting fractured zone as well as the height. The highest layer, where the water loss rate difference occurred, is the maximum height of the water-conducting fractured zone.

From the application data analysis, the maximum height of the water-conducting fractured zone (9.3m) was obtained. And this result was confirmed in later mining operations.

Actually, a work team adopted the electric resistivity method (ERM) to detect the mining induced water-conducting fractures and water storage location in overlying and underlying strata. Their detection result shows that the maximum height of the water-conducting fractured is 9.45m. The results are similar but not exactly the same. We believed that there are two reasons that may lead to the difference between the results. 1) The water-conducting fractured is formed, but so small that it is nearly closed so it can't be detected by DEB. This will make the DEB to have a relatively small water-conducting height compared to the ERM. 2) ERM operated after DEB several days. The time difference of the two detection methods can also give different results. As all know, the stress equilibrium around the goaf has a redistributed process after mining. The process undergoes in an uneven speed before the stress gets balanced again. The overlying strata may crack along with the process, during which the water-conducting fractured zone develop. Once the cracks formed, it can't disappear in a short time. That is to say, the water-conducting fractured height in the overlying strata will increase after mining during the process of stress redistribution.

In this view, the ERM which operated after the DEB had a higher water-conducting fractured height than DEB.

However, with certain detection methods, the measured water-conducting height can decreased because of the accuracy of the detection method. Once a crack is formed in the process of stress redistributed, it will exist in the whole process and can become smaller or larger depending on the pressure change during the process. If the crack is located in the front of the water-conducting fracture zone and becomes so small that it is beyond the scale the instrument to detect, a relatively small water-conducting height will be obtained.

Compared with the ERM as well as the other methods (such as ultrasonic wave, acoustic scan, hole televiewer etc.), the DEB is easier to operate and also gives high quality accurate results. When the mining face is full of water, which often occurred, the operation of ERM will be badly affected. The need for professional staff and special software for the ultrasonic wave, acoustic scan and hole televiewer detection methods are not available for most small coal mines in China. Therefore, using the DEB to detect water-conducting fractured zone is a best choice.

5. Conclusions

Coal mining operations in China are often threatened by groundwater invasion. It is of crucial importance to determine the height of water-conducting fractured zones induced by mining under aquifers. Field detection is the main methods to determine the height. A simple method that can work in small space mining panels and gassy condition is badly needed, especially in small mining operations. A case study for coal mining beneath water-bearing alluvium was given. The DEB was applied in the field to detect the height of mining-induced strata water-conducting fractured zones. The research with the DEB and the data collection was done at the Taiping Coal Mine.

The results show that the DEB can work very well in the upward inclined boreholes drilled from underground roadways. Compared to the ERM, the DEB also has a high quality accuracy rate. The DEB can also clearly show the process of the water-conducting fractured change over time.

The DEB can work well in water filled mining panels and gassy condition where some detection methods would be limited. These situations often occur in Chinese smaller coal mines where most highly technical instruments are not available because of the lack of professional staff or computer software, particularly in mid size or small coal mines. The DEB provides an efficient and convenient technique to determine the water-conducting fractured zone height in mining beneath aquifers due to its' convenient and easy operation in gassy condition. The DEB promises to be widely applied under similar conditions in other parts of the world.

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